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SUMMARY OF LANDING GEAR INITIAL FLAWS

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AIR FORCE FLIGHT DYNAMICS LABORATORY
AIR FORCE WRIGHT AERONAUTICAL LABORATORIES
AIR FORCE SYSTEMS COMMAND
WRIGHT-PATTERSON AIR FORCE BASE, OHIO 45433

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This technical report has been reviewed and is approved for publication.

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This report briefly summarizes the results of a field survey conducted by AFFDL and McDonnell Douglas at Ogden ALC (Hill AFB), 21-24 September 1976. The objective of the survey was to identify crack-like damage that had resulted in structural failures in landing gear components. This survey was based on depot metallurgical reports from 1971 to August 1976 and discussions with Ogden (ALC) depot maintenance engineering personnel and laboratory metallurgists.

FOREWORD

This report summarizes a survey performed under Air Force Contract F33615-76-C-3133, "Environment-Load Interaction Effects on Crack Growth". The contract is administered under the direction of the Air Force Flight Dynamics Laboratory by Dr. Joseph P. Gallagher (AFFDL/FBE), Project Engineer.

The Structural Research Department of McDonnell Aircraft Company (MCAIR) has responsibility for performance of the program. The principal author of this report is W. T. Fujimoto, MCAIR, who, along with Dr. Gallagher, conducted the field survey at Hill AFB. R. J. Kotfila, MCAIR, assisted in the metallurgical evaluations required in the survey summarization.

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TABLE OF CONTENTS

SECTION I

INTRODUCTION

This report briefly summarizes the results of a field survey conducted by AFFDL and McDonnell Douglas at Ogden ALC (Hill AFB), 21-24 September 1976. The objective of the survey was to identify crack-like damage that had resulted in structural failures in landing gear components.

The term crack-like damage is used to characterize a latent damage site from which there is negligible crack initiation time to a specified "initial" crack configuration that might be used in crack propagation - life analyses. Life analyses conducted in this manner can be used to scope the impact of various types of damage. The objective of the survey is to define the size and shape of these "initial" flaws and the various types of damage observed up to the present.

During the first phase of the survey, depot metallurgical laboratory reports from 1971 to Aug 1976 were reviewed to identify the causes of damage and to obtain estimates of the range of flaw sizes and shapes for each cause. The metallurgical laboratory reports were excellent for this purpose as they consisted, in most cases, of a brief history of the problem, optical or transmission electron microscope photomicrographs of the fracture surfaces and pertinent metallurgical information such as alloy, chemical composition, surface condition and hardness. From these reports the basic causes of initial damage were found to be (1) damage due to processing operations, (2) latent material defects, (3) mechanical damage and (4) crack growth from corrosion pits.

The next phase of the survey required the determination of a single initial flaw size and shape which was representative of the range of initial damage observed for each cause. To determine these geometries, "ball park" estimates of the sizes and shapes for each cause were prepared; these estimates were then critiqued and refined during separate group discussions with the depot maintenance engineering personnel responsible for investigating the problem and with the laboratory metallurgists in order to arrive at engineering estimates which were consistent with their experience.

The initial flaw geometry estimates, as determined by this process, will be used to define conditions for tests to be performed in this program. These estimates will also be used by the Ogden Air Logistics Center as a basis for further evaluation using metallurgical examinations of landing gear components as a continuing procedure, permitting refinement of the geometry estimates at a later date.

SECTION II

BACKGROUND

The objective of this program is to systematically investigate chemical environment-load interaction effects on crack propagation behavior. The program will be focused by developing a set of design guidelines and criteria for a durability and damage tolerance control plan for landing gear structural components. Current analytical life prediction capability will be assessed in conjunction with experimentally developed crack growth behavior. The program will act as a test of prediction capability and will establish the necessary guidelines and criteria.

In Phase I, Initial Flaw Characterization, a field survey has been conducted in order to catalog the size, type, and locations of flaws in landing gear components. This summary is summarized herein. After cataloging the flaws, these flaw geometries will be compared with those specified in MIL-A-83444.

In Phase II, Algorithm Development, a crack growth prediction capability will be developed through analysis and test that will account for environment and load interaction effects. The Willenborg model is the basis of continued model development. The materials for the program are HP-9Ni-4Co-.30C and 300M steels, and 7075-T6 and 7049-T73 aluminums. Crack growth tests will be performed on eighty specimens.

In Phase III, Verification Test Program, a flight-by-flight test stress history has been prepared for a landing gear component. The F-15 main landing gear has been selected as an "example" gear for the purposes of establishing the stress values and estimating times associated with the stress conditions. This history is based on the design loads for the gear, and not on field measurements. Using the prediction capability developed in Phase II, crack life predictions will be prepared for the verification test specimens. Subsequent to completion of these predictions, eight tests will be conducted. Two additional tests will be conducted subsequent to the completion of the first eight tests. The initial flaw geometry estimates obtained in Phase I will be used to define the initial flaw sizes to be used in the crack life predictions, and verification tests.

In Phase IV, Formulation of Guidelines, the experimental data will be evaluated and summarized to develop recommendations for a Durability/Damage Tolerance Control Plan for landing gear structure. Structural criteria that can be used in landing gear design will be defined and the chemical environment for landing gears will be outlined.

SECTION III

DISCUSSION

The initial flaw geometries, as determined thru the field survey, are summarized in Table I for each of the initiation mechanisms. The flaws are idealized as elliptical or part elliptical with the dimensions of the principal axes shown in Table I. Cracks initiating at multiple origins are idealized as a single equivalent crack.

One exclusion from the summary table is damage caused by hydrogen embrittlement of steels. The reason for this exclusion is that while hydrogen embrittlement results in delayed crack formation much like stress corrosion cracking, the crack formation is much more sudden than the latter, with component rupture occurring in many cases virtually simultaneously with crack formation. The absence of a stable, sub-critical, crack growth phase precludes the identification of an initial flaw size.

Damage Due to Processing Operations

Damage due to processing operations was observed primarily on steel components and could be categorized as (1) localized overtempered martensite, (2) localized untempered martensite, and (3) chrome cracking. Damage is caused during the plating or replating of close tolerance wear or sealing surfaces. The localized overtempered or untempered martensite condition occurs either during excessively severe grinding of the base metal in preparation for the chrome plating, or during finish grinding of the plated surface. The localized overtempered martensite condition is the less critical of the two and occurs when the grinding causes an overtempered surface layer with loss of strength and durability. Cracks which form in this layer usually initiate at multiple origins and can be characterized by a shallow surface flaw geometry.

Although a crack may not form at the time of overtempering, the material is highly susceptible to cracking by cyclic fatigue or by stress corrosion and a flaw may be assumed to exist for purposes of damage tolerance analyses.

The untempered localized martensite condition results when the grinding is severe enough to cause the steel to exceed the transformation temperature and become embrittled upon cooling. Damage associated with this condition is more severe than for the overtempered case since, in addition to the "quench" cracks formed in the embrittled surface layer, a transition zone of overtempered martensite exists between the untempered zone and the undamaged material. For this reason the initial flaw depth is assumed to be twice that of the depth for the overtempered case.

TABLE I
INITIAL FLAWS FOR LANDING GEAR COMPONENTS

Cause of Damage	Dimensions (in)	Comments
Processing Operations		
• Localized Overtempered Martensite	0.10, 0.003	Occurs in steel during grinding operations
• Localized Untempered Martensite	0.10, 0.008	Occurs in steel during grinding operations
• Chrome Cracking	0.10	Crack depth equal to depth of chrome layer
Latent Material Defects		
• Inclusions	0.125, 0.005	
• Forging Defects	0.10, 0.020	Dimensions shown are for forging laps
Mechanical Damage		
• Field Induced Damage in Steel	1.0, 0.005	
• Field Induced Damage in Aluminum	0.25, 0.02	
• Shop Induced Tool Marks	0.50, 0.003	
Corrosion		
• Corrosion Pit as Initiation Site for Stress Corrosion Cracking in Aluminum	0.020, 0.010	Depth of crack approximately half that of compressive layer induced by shot peening
• Corrosion Pits as Initiation Site for Stress Corrosion Cracking in Steel	0.010, 0.005	Depth of crack approximately half that of compression layer induced by shot peening
• Corrosion Pit as Initiation Site for Fatigue Crack Growth	0.01, 0.005	Occurs only in fatigue critical regions

GP77-0677-18

There are two types of chrome cracking: micro and macro. Micro-cracking normally is not visible without magnification, and occurs under ideal plating conditions whenever the plating thickness is 0.0001 inch or greater. Such cracking is a normal condition, and is not associated with faulty process controls. Macro-cracking of the chrome layer occurs during the finish grinding, or during the chrome deposition process due to faulty process controls. By itself, macro-cracking does not pose a structural problem; however, any macro-crack that completely extends through the chrome layer acts as a stress riser for formation of fatigue cracks in the base metal and also exposes material to environmental attack and subsequent stress corrosion cracking. For this reason the depth of the initial flaw is assumed to be equal to the chrome thickness.

Latent Material Defects

Latent material defects include inclusions and forging laps. Inclusion problems vary with material type with steel alloys posing more of a problem than aluminum alloys.

Mechanical Damage

Shop induced mechanical damage typically is characterized by sharp indentations or scratches which are sharp flaws per se. Field induced mechanical damage takes the form of permanent indentation due to impact with a blunt object. The indentation by itself does not act as a crack, however, the residual tension stresses in the vicinity of the indentation act as the driving force for nucleation and propagation of stress corrosion cracking. Consequently, the equivalent sharp flaw used to characterize field induced mechanical damage is typical of the flaw that would exist after a suitable initiation phase, not of one that was actually induced at the time of the damage.

Damage Due to Corrosion Pitting

Damage due to corrosion pitting is a time dependent phenomenon and its severity often depends upon maintenance frequency. Normal depot repair procedure is to polish or grind out pits at the time of overhaul; however, if pitting is not detected in time, the pits act as sites for crack initiation under cyclic loading or for stress corrosion cracking.

Fatigue crack initiation from corrosion pits occurs primarily in fatigue critical regions such as those with geometric stress risers or high

load levels. The initial flaw size shown is typical of those occurring in the time between overhaul or teardown inspection.

Stress corrosion cracking is not as dependent upon criticality of location, and can occur wherever a corrosive environment exists. Landing gear components are normally shot peened, and stress corrosion cracking does not pose a problem until the corrosion pitting has extended through the compressive layer induced by the shot peening; consequently the depth of the initial flaw is assumed to be equal to the depth of this compressive layer.

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